Editorial

Sepiapterin Treatment in Atherosclerosis
Margaret M. Tarpey

Tetrahydrobiopterin (BH₄) plays an important role in functional and metabolic cellular homeostasis, with additional effects on proliferation, immune responsiveness, and neuronal activity. Mutations in either de novo biosynthetic or regeneration (salvage) pathways result in BH₄ deficiency associated with diminished levels of serotonin and dopamine with progressive neurologic symptoms. The phenotypic presentation of these synthetic mutations can be predicted in large part by the role of BH₄ as an obligatory cofactor in phenylalanine, tryptophan, and tyrosine hydroxylases (the rate-limiting enzymes for catecholamine and serotonin synthesis). The function of BH₄ in these aromatic amino acid hydroxylases involves redox-active donation of electrons and reductive enzyme activation and is associated with a tightly coupled system for regeneration of BH₄ from the oxidized dihydrobiopterin.

More recently, partially oxidized analogues of BH₄ have been shown to also enhance rates of superoxide formation from purified eNOS in the presence of saturating l-arginine concentrations, suggesting that the ratio of reduced and oxidized biotyper may be physiologically important in determining rates of NO production versus uncoupled superoxide formation from eNOS.

The increase in oxidant formation that appears to accompany most, if not all, disease processes associated with endothelial-dependent vascular dysfunction may potentially be a result of inadequate BH₄ concentrations within the vasculature, with ensuing uncoupling of eNOS, increased superoxide formation and diminished NO formation. Thus, there is intense interest in the potential for BH₄ to modulate eNOS activity. Numerous groups have recently reported beneficial effects of acute (≤60 minutes) administration of BH₄ or analogs such as sepiapterin on endothelial function in both clinical and experimental models of hypercholesterolemia, atherosclerosis, hypertension, and cigarette smoking. Additionally, the beneficial effects of vitamin C administration on endothelial function are in part due to stabilization of intracellular BH₄ with resultant enhanced NO bioactivity. A similar mechanism of BH₄ stabilization may underlie the influence of folate supplementation on eNOS activity.

Alterations in BH₄-dependent eNOS activity have also been implicated in diabetic vascular dysfunction where sepiapterin has been reported to diminish eNOS-derived superoxide in human vascular segments. Acute administration of a BH₄ analog augmented endothelial-dependent relaxation in a streptozotocin model of diabetes. Spontaneously diabetic BB rats have diminished GTP-cyclohydrolase 1 activity and decreased BH₄ levels, while sepiapterin treatment for 48 hours normalized BH₄ levels and increased NO production from endothelial cells isolated from diabetic BB rats. In an insulin-resistant rat model, chronic oral administration of BH₄ also increased vascular BH₄ content and improved endothelial-dependent vascular function. Given these positive outcomes after administration of BH₄, either longer term in vitro exposures or chronic administration studies are warranted in models of atherosclerosis.

In this issue of Arteriosclerosis, Thrombosis, and Vascular Biology, Vasquez-Vivar et al report their interesting findings on the influence of 6 hours sepiapterin incubation on vascular BH₄ levels and endothelial function in vessels isolated from rabbits fed a high-cholesterol diet. They demonstrate a marked reduction in vascular BH₄ content in hyperlipidemic vessels compared with controls, which could be restored by incubation with sepiapterin. These findings are in agreement with the relatively few other studies reporting on BH₄ content in diseases associated with vascular dysfunction. While vascular BH₄ levels have been reported to be

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In addition to its role in the biosynthesis of monoamine neurotransmitters, BH₄ serves as an essential cofactor in all isoforms of nitric oxide synthases (NOS), with the Km for BH₄ for NOS several orders of magnitude lower than for the aromatic amino acid hydroxylases: NOS, ≈0.3 μmol/L vs ≈3 μmol/L for phenylalanine hydroxylase, ≈30 μmol/L for tyrosine hydroxylase and tryptophan hydroxylase, suggesting tight coupling of the cofactor with enzyme. However, the precise function(s) of BH₄ in NOS enzymatic activity is not as well defined as in the aromatic amino acid hydroxylases and may vary according to enzyme isoform. For endothelial NOS (eNOS), BH₄ has been reported to modulate the heme iron environment and stabilize and increase L-arginine binding, thus resulting in allosteric modulation of enzyme activity. The importance of BH₄ in regulating protein dimerization, while critical in iNOS, is diminished for eNOS. Importantly, eNOS has been demonstrated to generate superoxide in a calcium/calmodulin-dependent fashion that is influenced by BH₄ levels, as well as the availability of L-arginine substrate. This NADPH-dependent formation of superoxide anion in the absence of NO production has been referred to as uncoupling of NOS activity. Superoxide formation from eNOS is critically controlled by BH₄ with increasing production of superoxide occurring at low levels of reduced perin, even in the presence of L-arginine. It is available at http://www.atvbaha.org

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normal in spontaneously hypertensive rats (SHR) before the development of hypertension, BH4 levels are decreased in SHR with established hypertension.30,31 Several models of diabetes have also reported decreased vascular BH4 content.27,28

In contrast to the improvement of endothelial function seen in acute studies, however, long-term exposure to sepiapterin resulted in a further derangement in response to either acetylcholine or the calcium ionophore A23187, while endothelial-dependent function was not altered. These data are similar to those reported by Tsutsui et al32 in which canine middle cerebral arteries exhibited diminished relaxation to A23187 after 24-hour incubation with 100 μmol/L sepiapterin. In that study, the authors concluded that the inhibition of endothelial-dependent relaxation was due to enhanced generation of superoxide anion, as exogenous superoxide dismutase (SOD) ameliorated the effects of sepiapterin. It is well-recognized that BH4 itself can redox cycle and thus generate superoxide.33 This effect is likely to be enhanced in the setting of vascular relaxation studies, in which the O2 concentration is typically 95%. However, in the present report, only the hyperlipidemic vessels demonstrated a sepiapterin-dependent inhibition of endothelial-dependent relaxation. It should be noted that the normal vessels did not demonstrate an increase in BH4 content after incubation with sepiapterin, while the rise in BH4 content with sepiapterin supplementation did not exceed levels seen in control vessels. If the effects on vessel relaxation are secondary to BH4 autoxidation, this would suggest that there is also at least a relative deficiency of SOD in the hyperlipidemic vessels. Alternatively, in the face of a functionally abnormal eNOS, could sepiapterin supplementation result in sepiapterin-dependent superoxide generation from eNOS itself, as has been described for the purified enzyme?34 The effect of either exogenous SOD or a cell-permanent SOD mimetic would be informative.33 On the other hand, BH4 can serve to scavenge superoxide with a rate constant of 10^5 M^-1 · s^-1 and reacts with peroxynitrite.12,19,34 Thus, the effects of sepiapterin are the result of extent of salvage pathway activity and conversion to BH4, balanced with rates of BH4 autoxidation and consumption by peroxynitrite, as well as sepiapterin binding to eNOS in competition with BH4.

The inhibitory effect of 6 hours of sepiapterin treatment also contrasts with 2 studies of 8-week in vivo administration of BH4 demonstrating improved endothelial function in models of SHR and diabetes.29,31 Are these differences due to unrecognized secondary reactions of sepiapterin as opposed to BH4 itself? The report by Vasquez-Vivar et al29 opens new avenues of investigation with respect to the role of biopterin in vascular dysfunction.

References


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